Choosing the Maximum Permissible Diameter for Circles of Confusion

Many Depth of Field calculators treat the Maximum Permissible Diameter for Circles of Confusion as a *constant* within a given film format or digital sensor size instead of as a *variable*. This single oversight is responsible for much of the disappointment and mistrust photographers have when using Depth of Field tables, calculators, and of course, the engraved scales on their lens barrels, because it completely ignores the fact that Depth of Field, as perceived when looking at the final print, varies with enlargement factor and viewing distance. Many people have abandoned the use of Depth of Field calculators completely because they believe their experience has proven the math can't be trusted. The real problem is that the math they've been using failed to consider enlargement factor and viewing distance as variables affecting one's perception of Depth of Field.

Legions of photographers who understand the concept of DoF routinely make the mistake of assuming that one set of DoF calculations (one table, one spinning disk calculator, one set of lens engravings) will satisfy every possible combination of enlargement factor and print viewing distance for a given film format or sensor size. That's simply not true.

The following diameters are typically recommended as *constants* one can use when calculating DoF for the respective formats:

Format	**CoC Diameter Typically Recommended**
35mm	0.030 mm
6 x 4.5 cm	0.045 mm
6 x 6 cm	0.050 mm
6 x 7 cm	0.060 mm
6 x 9 cm	0.070 mm
4 x 5 in	0.100 mm
5 x 7 in	0.150 mm
8 x 10 in	0.200 mm

Table 1 – *CoC Constants Used with Various Formats*

Treating these as constants assumes that you will never crop your images, nor view the prints at any distance other than a fixed ratio of viewing distance to enlargement factor.

What CoC diameters are lens manufacturers using to calculate the DoF scales engraved on their lens barrels?
Quoting p.131 of "Basic Photographic Materiels and Processes" by Stroebel, Compton, Current, and Zakia (c1990 Focal Press):

> "Permissible circles of confusion are generally specified for a viewing distance of 10 inches, and 1/100 inch is commonly sited as an appropriate value for the diameter."

This post-enlargement value of 1/100 inch is equivalent to 0.254 mm in the final print, permitting a resolution of only 4 line pairs per millimeter (lp/mm).

> "A study involving a small sample of cameras designed for advanced amateurs and professional photographers revealed that values ranging from 1/70 to 1/200 inch were used -- approximately a 3:1 ratio."

That 3:1 ratio varies from 0.363 mm to 0.127 mm in the final print, permitting resolutions of 2¾ to 8 lp/mm. The rotating-disk Depth of Field calculators published by Kodak in their *Photoguides* use a generous value of 1/100 inch (4 lp/mm) which, in my opinion, is satisfactory only at a viewing distance of at least 20 inches.

Most people agree that the average adult with healthy vision can resolve no more than about 5 to 8 lp/mm (line pairs per millimeter) at a viewing distance of 10 inches. Assuming a viewing distance of 20 inches, for example, we wouldn't need more than 4 lp/mm on print, after enlargement (half of the 8 lp/mm needed to survive closer scrutiny at 10 inches).

At this point, it should be apparent that the maximum diameter you are willing to permit on-film for CoC's must be calculated by first deciding what resolution you hope to achieve in the final print and this, in turn, can not be determined without considering the anticipated enlargement factor and minimum viewing distance at which your prints might be examined. It should also be apparent that the *constants* shown in Table 1 above for various formats can not possibly satisfy every combination of print size and viewing distance one might produce with a given film format or sensor size.

It's somewhat subjective, but I prefer to keep the diameter of CoC's below 1/175 inch in a print to be viewed at a distance of 10 inches. This is toward the more critical end of the range used by manufacturers and will permit a resolution of almost 7 lp/mm in the final print. I've found this to be sufficient to satisfy nearly anyone's demands for "sharpness".

Not only do most depth of field calculators deprive you of the ability to select your own permissible diameter for CoC's, they also make no effort to account for cropping to aspect ratios that are different than that of the original format. In other words, when calculating depth of field, the diagonal of that portion of the image that will be lifted to produce the final print should be used, not the full image diagonal. If you are routinely cropping your 35mm slides to make 8x10, 11x14 or 16x20 prints (4:5 aspect ratio), then your format diagonal is not that of the full 24x36mm image area. The nominal 4:5 crop uses only a 24x30mm portion of the full image and that means the depth of field calculation should use a format diagonal of 38.42mm not 43.27mm. Here's the impact of using the wrong diagonal for a 100 mm lens at f/8 seeking a maximum CoC of 1/175 inch after magnification to a 10-inch diagonal print:

Image Diagonal	Near Sharp	Hyperfocal Distance	Far Sharp
38.42 mm	93.40 feet	186.80 feet	Infinity
43.27 mm	82.93 feet	165.86 feet	Infinity

Table 2 – *Difference in DoF calculated with and without consideration for the affect cropping has on enlargement factor*

That's a ten-foot difference to the Near Sharp, just due to the difference in magnification when cropping to a 4:5 aspect ratio. If we use Kodak's spinning-disk depth of field calculators that have fixed the maximum permissible diameter for CoC's at a sloppy 1/100th inch (for magnification to a 10-inch diagonal print) and which assume no cropping will be done, we would be told our Near Sharp, using same example, is 47.39! That's nearly half the distance to the 82.93-foot Near Sharp we calculated when accounting for a 4:5 crop and selected a CoC of 1/175 inch! So is it any wonder that people are disgusted with DoF calculators?

When I use 1/175 inch as the maximum diameter for CoC in a 10-inch diagonal print to be viewed at a distance of 10 inches, this works out to be OK for any size print as long as the viewing distance is increased proportionally. But, if I know in advance that the print will be viewed at a distance less than the print diagonal, I have to DECREASE the CoC diameter proportionately. I have a lot of prints hanging in a track-lighted hallway in my home where the width of the hallway forces viewing distances less than 36 inches and, in practice, encourages viewing distances of as little as 10 inches. This kind of scrutiny demands 11x14 or smaller prints even from 6x7 format, but I do have several 16x20's in that hallway that can take the punishment.

I have, on occasion, specified CoC's as small as 1/350 inch (one half the diameter of 1/175 inch) for 16x20 prints to be viewed at a distance equal to half their 25-inch diagonal. Sticking with the above example (35mm format,

cropped to 24x30, using 100mm lens at f/8), this runs my Near Sharp out to 186.80 feet with the Far Sharp at Infinity, but Kodak's DoF calculator would still say 47.39 feet! The Kodak spinning disk calculator would have me set my focus index at a distance that is twice this Near Sharp, or 94.78 feet and under the circumstances I've just described (any size print viewed at a distance equal to half its diagonal), this means the REAL Near Sharp would be 75.60 feet and the REAL Far Sharp would be at 127.0 feet NOT infinity! Again, it's not surprising people don't trust DoF calculators.

Recommendations: Use this formula to determine the Maximum Permissible Diameter for Circles of Confusion, for use in a DoF calculator that permits its specification as a variable:

Max. Permissible CoC Diameter (mm) = 1 / desired resolution in lp/mm / anticipated enlargement factor

For example, if you want to achieve a resolution of 7 lp/mm in an 8x10 print made with a 24x30mm crop from fullframe 35mm format, your enlargement factor would be 8x and thus…

Max. Permissible CoC Diameter = 1 / 7 / 8 = 0.018 mm

That's significantly more demanding than the 0.030 mm value typically recommended for 35mm format.

An Excel-based Depth of Field calculator that takes into account *all* the variables affecting perceived DoF can be downloaded from the Not Just Another Depth of Field Calculator! link on this page:

http://home.globalcrossing.net/~zilch0/tools.htm

I encourage you to use this spreadsheet to calculate and print a DoF table for every combination of format, focal length, print size, viewing distance and desired print resolution you anticipate. Seriously! It's not that tough. Armed with these printed DoF tables in the field, you will be able to determine *precisely* the aperture and focus distance necessary to deliver the resolution *you* desire in the print size of *your* choosing at the viewing distance *you* want to satisfy.

This spreadsheet also encourages you to measure the actual image area produced by the cameras you own, enter those dimensions (or take the ones given) and then calculate diagonals for maximum crops to get popular aspect ratios like 1:1, 4:5, 5:7 and 11:14. You can even specify a unique aspect ratio.

It also calculates the aperture at which Airy disks start becoming visible due to diffraction, the aperture at which the quest for depth of field should be achieved by other methods (increasing subject distance, using tilts, etc.)

If you would prefer to use a different tool for calculating DoF and that tool permits you to specify the maximum permissible on-film (or on-sensor) CoC diameter, you can use the spreadsheet titled Maximum Permissible Circle of Confusion Calculator to determine the value you should use in your DoF calculations. It can also be found at:

http://home.globalcrossing.net/~zilch0/tools.htm